International Journal of Physics
and Research (IJPR)
ISSN(P): 2250-0030; ISSN(E): 2319-4499
Vol. 4, Issue 6, Dec 2014, 27-36
TJPRC Pvt. Ltd.

NEUTRON YIELD CALCULATION FOR GALLIUM-66 FROM DIFFERENT REACTIONS

B. M. SAIED[1], A. A. HUSSEIN[2], I. N. IBRAHIM[3], M. N. SARSAM[4], & R. F. RABEE[5]

[1,2,5]Department of Physics, College of Education Ibn Al-Haytham, University of Baghdad, Iraq

[3]Ministry of Education, Iraq

[4]Al-Salam University College, Baghdad, Iraq

ABSTRACT

The calculated neutron yields are very important in analyzing radiation shielding of spent fuel storage, transport and safe handling. The cross sections of $^{66}_{30}Zn(p,n)^{66}_{31}Ga$, $^{67}_{30}Zn(p,2n)^{66}_{31}Ga$, $^{68}_{30}Zn(p,3n)^{66}_{31}Ga$, $^{65}_{29}Cu(a,3n)^{66}_{31}Ga$, $^{64}_{30}Zn(a,n+p)^{66}_{31}Ga$, $^{66}_{30}Zn(d,2n)^{66}_{31}Ga$, $^{nat}_{29}Cu(a,x)^{66}_{31}Ga$ and $^{nat}_{30}Zn(p,x)^{66}_{31}Ga$ are calculated for different energies using different sets of programs using Matlab language. The weight average cross section was then used to calculate the neutron yields .The empirical formula was then suggested for calculate total neutron yield for each reaction. Different type of expressions have been tried to fit the weighted average (W.A) of n-yield data. For the first time new polynomial expressions were found relating n-yields with α-energy.

KEYWORDS: Neutron Yield, ^{66}Ga Production, Cross Section Evaluations, Weighted Average

INTRODUCTION

The problems of nuclear technology are many: one of them is the development of analytical methods for the control and protection from nuclear radiation; another is the production of neutron and isotopic energy sources based on radiation emitting of radionuc1ides.This kind of information must be known to an accuracy of approximately 10% for particle energies ranging from reaction thresholds to 10 MeV for target nuclei with z$\leq$20[1]. Medical applications of nuclear radiation are of considerable interest to the IAEA. Cyclotrons and accelerators, available in recent years are in increasing number in different countries, they are being used for the production of radioisotopes for both diagnostic and therapeutic purposes. The physical basis of this production is described through interaction of charged particles, such as protons, deuterons and alphas, with matter. These processes have to be well understood in order to produce radioisotopes in an efficient and clean manner. In addition to medical radioisotope production, reactions with low energy charged particles are of primary importance in nuclear astrophysics there is interest in numerous reaction rates to understand the nuclear reactions in the cosmos [2]. Elemental gallium is not found in nature, but it can obtained by different nuclear reactions. Gallium is used in electronics, in microwave circuits and high-speed switching circuits, in infrared circuits in blue and violet light-emitting diodes and in diode lasers. The cross section data of $^{66}_{30}Zn(p,n)^{66}_{31}Ga$ are obtained from the works published by F. Szelecsenyi.et.al[3] in the energy range (25.3- 99.5) MeV, F.Szelecsenyi.et.al[4] in the energy range (6.38- 25.72) MeV, B.S.Ishkhanov.et.al[5] in the energy range (4.78- 29.92) MeV, N.A.Demekhina.et.al[6] in the energy range (6.4- 21.1) MeV and F.E.Little.et.al[7] in the energy range (6- 35) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. The cross section data of $^{67}_{30}Zn(p,2n)^{66}_{31}Ga$ are obtained from the works published by F. Szelecsenyi.et.al[4]

in the energy rang (14.73- 25.71) MeV, A. Henrmannen[8] in the energy rang (17.94- 29.92) MeV, B.S.Ishkhanov.et.al[5] in the energy range (13.8- 29.5) MeV and O.V.Ogdankevich.et.al[9] in the energy range (13.6- 21.3) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction.The cross section data of $^{68}_{30}Zn(p,3n)^{66}_{31}Ga$ are obtained from the works published by F. Szelecsenyi.et.al[10] in the energy range (24.78- 99.26) MeV, T. Stoll et.al[11], in the energy range (25.7- 68.9) MeV, A.Hermanne.et.al[12] in the energy range (24.2- 33.9) MeV and T.E.Boothe.et.al[13] in the energy range (25.75- 29.92) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. The cross section data of $^{65}_{29}Cu(a,3n)^{66}_{31}Ga$ are obtained from the works published by V.N. Levkovskij[14] in the energy range (28.2- 46) MeV, A. Navin.et.al[15] in the energy range (29.1- 37.8) MeV, K. G. Porges[16] in the energy range (29.6- 37) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. The cross section data of $^{64}_{30}Zn\,(a,n+p)^{66}_{31}Ga$ are obtained from the works published by V. N. Levkovskij[14] in the energy range (18.4- 46) MeV, F. H. Ruddy and B. D. Pate[17] in the energy range (19.6- 36.9) MeV], and N.T. Porile[18] in the energy range (18.9- 39.6) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. The cross section data of $^{66}_{30}Zn(d,2n)^{66}_{31}Ga$ are obtained from the works published by J. Steyn and B.R. Meyer[19] in the energy range (9.7- 15.8) MeV, D.C. Williams and J.W. Irvine Jr[20] in the energy range (9.3- 15.4) MeV and J. L. Gilly.et.al[21] in the energy range (8.8- 11.6) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. The cross section data of $^{nat}_{29}Cu(a,x)^{66}_{31}Ga$ are obtained from the works published by F.Szelecsenyi.et.al[22] in the energy range (8.5- 36.3) MeV, F.Szelecsenyi.et.al[23] in the energy range (15.9- 58.1) MeV, F.Tarkanyi.el.al[24] in the energy range (7.5- 37.3) MeV, M. Sonck.et.al[25] in the energy range (9.9- 42.304) MeV and F.Tarkanyi.et.al[26] in the energy range (8.5- 40) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. The cross section data of $^{nat}_{30}Zn(p,x)^{66}_{31}Ga$ are obtained from the works published by F.S.Al-Salenh.et.al[27] in the energy range (3.7- 27.2) MeV, M. S. Uddin et.al[28] in the energy range (4- 39.6) MeV, F.Szenlencsennyi.et.al[29] in the energy range (6.42- 95.34) MeV and A. Hermanne[30] in the energy range (4.78- 29.29) MeV, these data are plotted, interpolated and recalculated in steps of 0.01 MeV using different sets of Matlab programs in order to obtain a weighted average value for this reaction. Knowledge of total neutron yield of heavy ions from thick target is important for estimating radiation damage by lost beam ions in high intensity accelerators. The cross sections used (σ_i) are the weighted average cross sections and their corresponding errors ($\Delta\sigma_i$) calculated according to the following expressions [31]:

$$\sigma_{w.a.}=\frac{\sum_{i=1}^{n}\frac{\sigma_i}{(\Delta\sigma_i)^2}}{\sum_{i=1}^{n}\frac{1}{(\Delta\sigma_i)^2}} \tag{1}$$

$$S.D=\frac{1}{\sqrt{\sum_{i=1}^{n}\frac{1}{(\Delta\sigma_i)^2}}} \tag{2}$$

The yield of neutrons per each incident particle Y_n for an ideal, thin and uniform target and non energetic beam of energy E is given by [32]:

$$Y(E_b) = \int_{E_{th}}^{E_b} \frac{\sigma(E)\,dE}{\frac{dE}{dX}} \qquad \ldots (3)$$

For each energy interval (E_b-E_{th}), the ratio of the cross section values by the energy loss $\frac{dE}{dX}$ $(\acute{E})$ calculated using the stopping power SRIM gives the yield for that interval, E_{th} is the reaction threshold energy and E_b is the average energy between two successive values.

RESULTS

- **The reaction** ${}^{66}_{30}Zn(p,n){}^{66}_{31}Ga$

The cross section data measured by [3-7], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 5 MeV up to 50 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 1 the weighted average cross section can be expressed by the following polynomial:

f(x)=439.1*exp(-((x-16.71)/5.181)^2)+88.76*exp(-((x-23.94)/3.436)^2)+ 128.9*exp (-((x-43.35)/11.41) ^2**)**

The obtained neutron-yield using SRIM codes in the chosen energy range are shown in figure 9.

- **The reaction** ${}^{67}_{30}Zn(p,2n){}^{66}_{31}Ga$

The cross section data of these reactions measured by [4, 5, 8, and 9], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 13 MeV up to 30 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 2 the weighted average cross section can be expressed by the following polynomial:

f(x) = 618*exp(-((x-29.3)/6.524)^2) +446*exp(-((x-37.3)/9.249)^2)

The obtained neutron-yield using SRIM code in the chosen energy range are shown in figure 10

- **The reaction** ${}^{68}_{30}Zn(p,3n){}^{66}_{31}Ga$

The cross section data measured by [16-19], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 24.5 MeV up to 70 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 3 the weighted average cross section can be expressed by the following polynomial:

F(x) = -0.4995*x^4 + 19.47*x^3 -264.3*x^2+1497*x-2948

The obtained neutron-yield using SRIM code in the chosen energy range are shown in figure 11

- **The reaction** ${}^{65}_{29}Cu(a,3n){}^{66}_{31}Ga$

The cross section data measured by [14-16], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 27.5 MeV up to 46 MeV in order to obtain the adopted cross section of this reaction. The results of

adopted cross section and the actual data are shown in figure 4 the weighted average cross section can be expressed by the following polynomial:

F(x) = 2.303e+4.1*exp(-((x-15.25)/3.8)^2)+55.66*exp(-((x-9.425)/2.287)^2)- 2.294e+4.05*exp (-((x-3.793) ^2) +34.96*exp (-((x-36.04)/27.58) ^2)

The obtained neutron-yield using SRIM code in the chosen energy range are shown in figure 12

- **The reaction** ${}^{64}_{30}\mathrm{Zn}\,(\mathrm{a}\,,\mathrm{n}+\mathrm{p})^{66}_{31}\mathrm{Ga}$

The cross section data measured by [14, 17, 18], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 20 MeV up to 40 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 5 the weighted average cross section can be expressed by the following polynomial:

f(x) = 1.916e+4*exp(-((x-14.38)/4.328)^2)- 1.871e+4*exp(-((x-14.4)/4.303)^2) +57.26*exp(-((x-26.87)/15.28)^2)

The obtained neutron-yield using SRIM code in the chosen energy range are shown in figure (13).

- **The reaction** ${}^{66}_{30}\mathrm{Zn}(\mathrm{d},2\mathrm{n})^{66}_{31}\mathrm{Ga}$

The cross section data measured by [19-21], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 9 MeV up to 15 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 6 the weighted average cross section can be expressed by the following polynomial:

f(x) = 244.4*exp(-((x-19.9)/2.685)^2) + 418.7*exp(-((x-23.69)/4.422)^2) + 183.0*exp (-((x-16.6)/1.853) ^2).

The obtained neutron-yield using SRIM code in the chosen energy range is shown in figure (14).

- **The reaction** ${}^{nat}_{29}\mathrm{Cu}(\mathrm{a},\mathrm{x})^{66}_{31}\mathrm{Ga}$

The cross section data measured by [22-26], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 8 MeV up to 58 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 7 the weighted average cross section can be expressed by the following polynomial:

F(x) = 127.4*exp(-((x-38.26)/1.687)^2)+153.5*exp(-((x-36.38)/4.824)^2)

The obtained neutron-yield using SRIM code in the chosen energy range are shown in figure 15

- **The reaction** ${}^{nat}_{30}\mathrm{Zn}(\mathrm{p},\mathrm{x})^{66}_{31}\mathrm{Ga}$

The cross section data measured by [27-30], have been plotted, interpolated, and recalculated in steps of 0.01 MeV from energy 5 MeV up to 30 MeV in order to obtain the adopted cross section of this reaction. The results of adopted cross section and the actual data are shown in figure 8 the weighted average cross section can be expressed by the following polynomial:

$$f(x) = 7.791*\exp(-((x-33.29)/0.4236)^2) + 4.05e+15*\exp(-((x+655.9)/125.3)^2) - 625.7*\exp(-((x-22.72)/8.363)^2)$$

The obtained neutron-yield using SRIM codes in the chosen energy range are shown in figure (16).

CONCLUSIONS

The weighted average cross sections values indicate clearly the necessity to adopt such calculations which are very important for some problems such as neutron dosimetry, fuel burn-up and determination of isotope production. A complete dependency on individual or even collective experimental results are not recommended due to experimental deviations and errors and the impossibility of measurement for all the detailed interval of energy .This may be one of the important reasons to explain the observed deviations in some energy intervals of the international libraries. Thus using the weighted average cross sections one can obtain an accurate, complete and energy detailed cross section values and can implement the essential condensation calculation in terms of any energy interval which are essential for all kinds of reactor calculations. By using these adopted cross sections values together with stopping power from (SRIM) software the neutron yields empirical formulas were suggested for each reaction, where these polynomial expressions have been established and found to be most adequately fits the data.

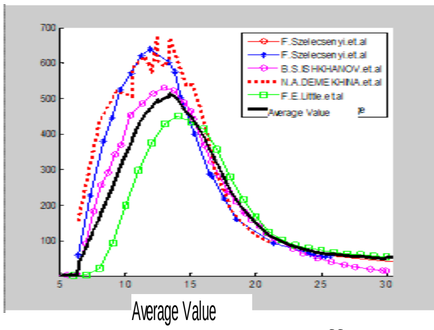

Figure 1: Cross sections of ^{66}Zn (p, n) ^{66}Ga

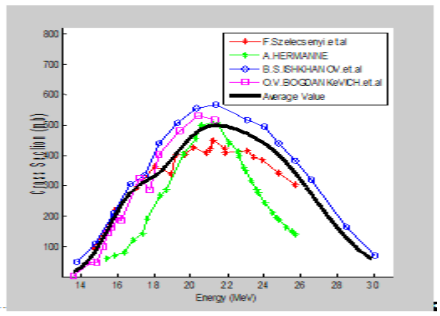

Figure 2: Cross sections of ^{67}Zn (p, 2n) ^{66}Ga

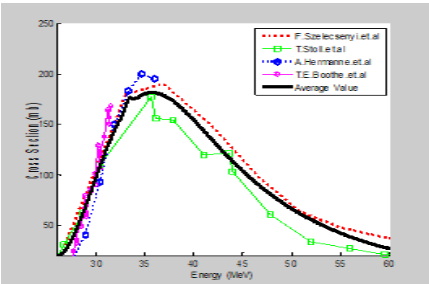

Figure 3: Cross Sections of ^{68}Zn (P, 3n) ^{66}Ga

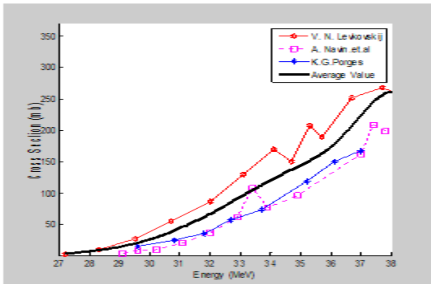

Figure 4: Cross Sections of ^{65}Cu (A, 3n) ^{66}Ga

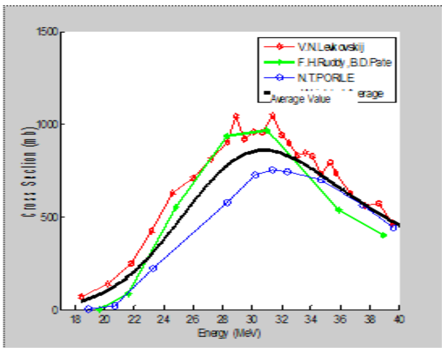

Figure 5: Cross Sections of ^{64}Zn (A, N+P) ^{66Ga}

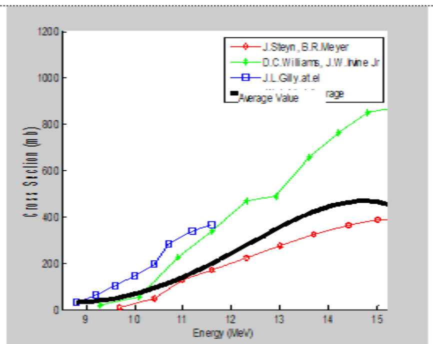

Figure 6: Cross Sections of ^{66}Zn (D, 2n) ^{66}Ga

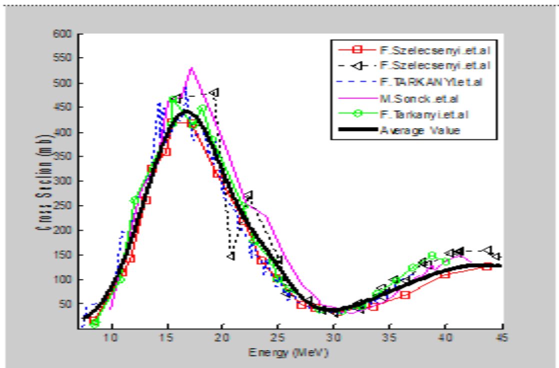

Figure 7: Cross sections of ^{0}Cu (a, x) ^{66}Ga

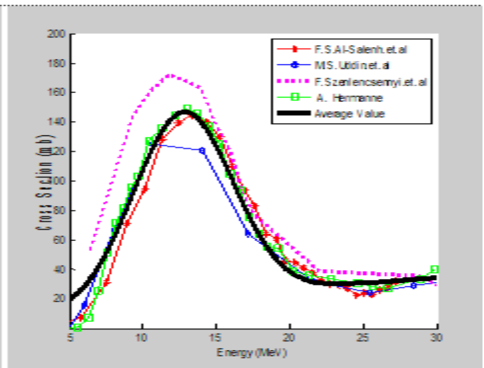

Figure 8: Cross sections of ^{0}Zn (p, x) ^{66}Ga

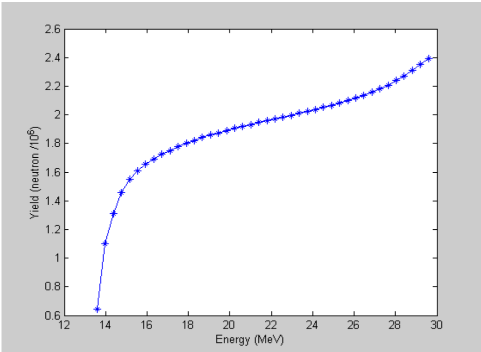

Figure 9: Total Neutron yield of ^{66Zn} (p, n) ^{66}Ga Reaction

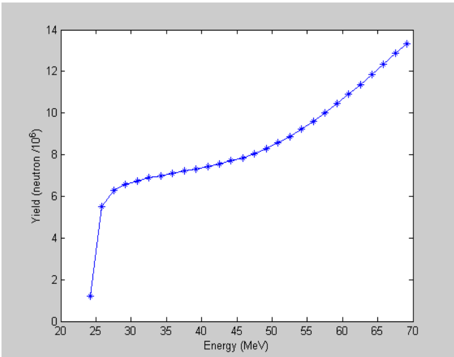

Figure 10: Total Neutron yield of ^{67Zn} (p, 2n) ^{66}Ga Reaction

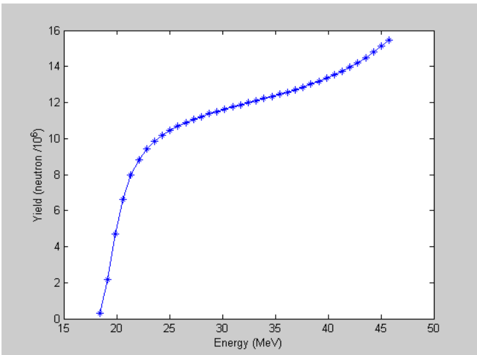

Figure 11: Total Neutron Yield of ^{68Zn} (P, 3n) ^{66}Ga Reaction

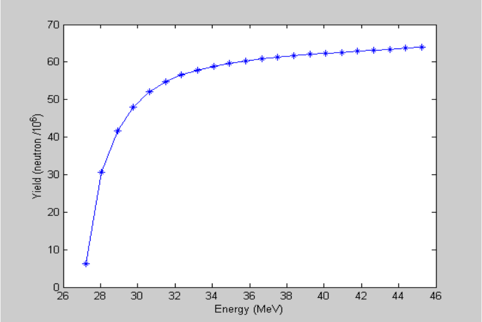

Figure 12: Total Neutron Yield of ^{65Cu} (A, 3n) ^{66}Ga Reaction

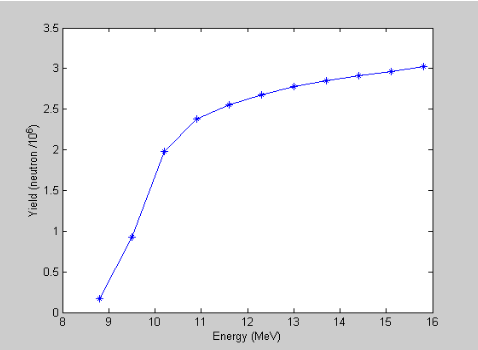

Figure 13: Total Neutron Yield of ^{64Zn} (A, N+P) ^{66Ga} Reaction

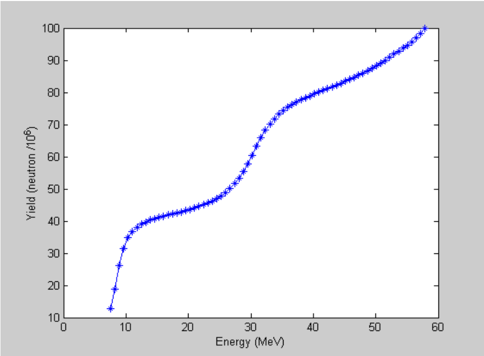

Figure 14: Total Neutron Yield of ^{66Zn} (D, 2n) ^{66}Ga Reaction

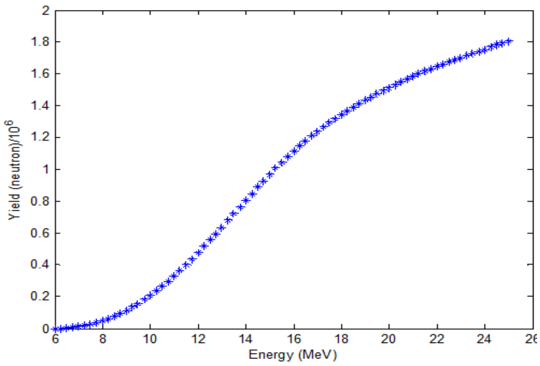

Figure 15: Total Neutron Yield of ^{Nat} cu (A, X) ^{66}Ga Reaction

REFERENCES

1. Vukolov, V. A; Chukreev, F. E. and Kurchatov, I. V, (1991), Atomic Energy Institute INDC (CCP)-331.

2. IAEA-TECDOC-1211Charged particle cross-section database for medical Radioisotope production: diagnostic radioisotopes and monitor reactions.
3. Szelecsenyi, F; Steyn, G. F. and Kovacs, Z, (2005), J, NIM/B, 234 (4): 375.
4. Szelecsenyi, F; Boothe, T. E; and Takacs, S,(1998), J, ARI, 49: 1005.
5. Ishkhanov, B. S; Kapitonov, I.M. and Lazutin, E. V, (1969), J, IZV, 33 (12): 2074.
6. Denmenkhina, N.A;Danagulyan, A.S. and Karapentyan, G.S,(2002), J,YF,65(2):390.
7. Little, F. E. and Lagunas-Solar, M.C, (1983), J, ARI, 34: 631.
8. Hermanne, A, 1994, Journal of Radioanalytical and Nuclear Chemistry, 20: 140.
9. Denmenkhina, N. A; Danagulyan, A. S. and Karapentyan, G. S, (2002), J, YF, 65 (2):390.
10. Szelecsenyi .F, Steyn. G. F, Kovacs.Z, VanDerWaltK. Suzuki T.N, Okada. K, Mukai. K, (2006) Nucl. Instrum. Methods in Physics Res, Sect.B Vol.27,Issue.2
11. Stoll, T; Kastleiner, S. and Shubin, Yu.N,(2002), Journal of Radiochemical Acta, 90:309.
12. Hermanne, A; Szelecsenyi, F. And Sonck, M, (1999), Journal of Radioanalytical and Nuclear Chemistry, 240: 623.
13. Boothe, T. E; Szelecsenyi, F. and Tavano, E, (1994), J, Nucl Data for Sci. and Techn, p.393.
14. Levkovskij, V. N, (1991) ,Book: Levkovskij, Moscow.
15. Navin, A; Tripathi, V.and Blumenfeld,Y,(2004), J, Nucl phys,70(4):044601.
16. Porges, K. G, (1956), J, phys.Rev, 101(1):225.
17. Ruddy, F. H. and Pate, B. D, (1969), J, Nucl phys. A, 127: 305.
18. Porile, N. T, (1959), J, phys. Rev, 115:939.
19. Steyn, J. and Meyer, B. R, (1973), J, ARI, 24:369.
20. Williams, D. C. and IrvineJr, J. W, (1963), J, phys. Rev, 130(1):265.
21. Gilly, J. L; Henriet, G. A. and PreciosaAlves, M, (1963), J, phys Rev, 131(4):1727.
22. Szelecsenyi, F; Kovacs, Z. and Nagatsu, K, (2012), Journal of Radiochemical Acta, 100, 5.
23. Szelecsenyi, F; Suzuki, K. and Kovacs, Z, (2001), J, NIM/B, 184(4):589.
24. Szelecsenyi, F Tarkanyi, F. and Takacs, S. (2000), J, NIM/B, 168:144.
25. Sonck, M; Van Hoyweghen, J. andHermanne, A, (1996), J, ARI, 47:445.
26. Tarkanyi, F; Szelecsenyi, F. and Kopecky, P, (1991), J, Nucl Data for Sci. and Techn, p.529.
27. Al-Salenh F. S, Al Mugrenn K. S, A. Azzam, (2007) Journ: Appliend Radiation and Isotopens, Vol.65, p.1101.

28. Uddin M. S, Khandakenr M. U, Kim K. S, Lenen Y.S, Kim G.N. (2007) J: Nucl. Instrum. Menthods in Physics Rens, Senct.B, Vol. 258, p. 313.

29. Szenlencsennyi, F; Stenyn, G.F; Kovacs, Z; Suzuki, K; Okada, K; Mukai K.(2005) J.: Nucl. Instrum. Menthods in Physics Rens, Senct.B, Vol.234, Issuen.4, p.375.

30. Hermanne A, (1998), J, ARI,) Journ: Appliend Radiation and Isotopens, Vol. 49, Issuen. 1, p.1005 (1998).

31. Y. Nagame, H. Nakahara, M. Furukawa, Journ Radio chimica Acta, Vol.46, p. 5 (1989).

32. Wrean, P. R. (1998) PhD thesis, California Institute of technology U. S. A.